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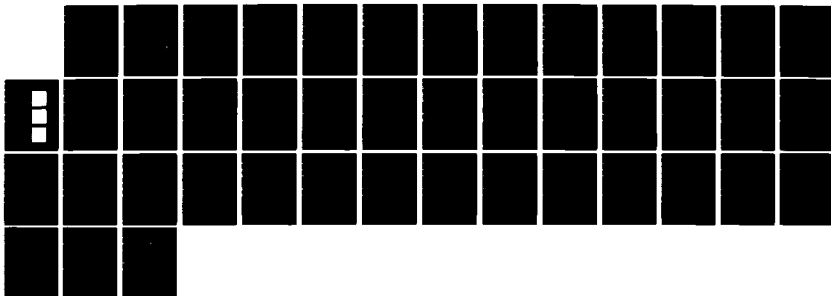
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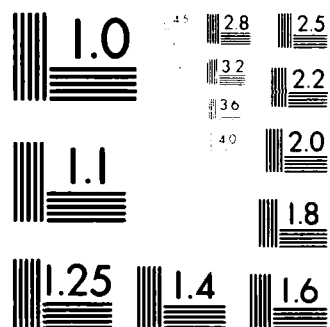
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) (1) A device has been developed (MIDAPT) that tests a subject's ability to track a target's motion in depth. The test has been encouragingly successful in predicting intersubject differences of pilots' flying performance in high-performance jet aircraft and in simulators. (2) We report evidence that human observers' acute discrimination of differences in size (about 5%) and orientation (about 0.3 deg) is achieved by comparing the outputs of two or more neurons, each of which is sensitive to a rather broad range of		

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sizes and orientations. We suggest that the human visual pathway contains size-opponent and orientation-opponent mechanisms, and that this can explain why subjects easily unconfound orientation, size and contrast in spite of the fact that the firing of cortical neurons is affected by all three parameters. Our evidence is that adapting to a grating of frequency  $S$  and orientation  $\theta$  had the following effects: (a) reduced sensitivity but slightly improved discrimination for gratings of frequency  $S$  and orientation  $\theta$ ; (b) reduced discrimination but almost unaffected sensitivity for a grating of different frequency or orientation. (3) We measured subjects' ability to detect a camouflaged object that was visible only when moving, and compared these data with similar measurements for conventional objects that were brighter than their surroundings. Temporal integration (Bloch's Law) was about 0.75 sec compared with 0.06 sec, and the spatial summation field area was about five times larger for motion-defined objects. These findings may be relevant to low-level flight, for example in helicopters, where ground features may be virtually indistinguishable except when moving. (4) Monocular ability to judge the direction of motion in depth was investigated by measuring the effect of adaptation to different directions of motion in depth for a target viewed with one eye. In contrast to binocular judgements of motion in depth, the results could be explained in terms of only two channels: one for frontal plane motion, and one for pure line-of-sight motion.

VISUAL SENSITIVITIES AND DISCRIMINATIONS  
AND THEIR ROLES IN AVIATION

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## 2a. OBJECTIVES

(1) Design visual tests based on the channel theory of visual processing, in particular tests of suprathreshold motion discrimination, and find whether these tests predict intersubject differences in flying performance.

(2) Explain how subjects are able to unconfound simultaneous changes in target orientation, size and contrast, and still achieve spatial discriminations of size and orientation that are considerably more acute than the bandwidths of spatial frequency channels or cortical neurons.

(3) Compare visual detection (i.e. visual acquisition) of camouflaged objects whose edges are defined by velocity differences with visual detection of objects that are brighter or dimmer than their surroundings, and find whether these two kinds of object detection can be explained in terms of a single neural mechanism or whether two kinds of brain mechanism are implied.

(4) Compare monocular and stereoscopic visual responses to motion in depth, and find whether the human visual pathway contains monocular channels tuned to different directions of motion in depth.

## 2b. STATUS OF THE RESEARCH EFFORT

### (i) Motion-in-depth tracking technique and perturbed tracking technique

The NRC Committee on "Emergent Methods of Visual Assessment" has listed three emerging techniques for visual assessment. Our motion-in-depth tracking technique is one of these three. This is the technique we described in Ref 98. The motion-in-depth tracking device was patented by the U.S. Air Force (Regan & Beverley, U.S. Patent 4,325,697). We have used the technique in attempting to predict individual differences in subjects' ability to judge the motion and location of objects in three dimensions, especially as regards individual differences in flying performance. This work is described under

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MATTHEW J. KOFFER  
Chief, Technical Information Division

item (v) below. Other groups have also requested to use the motion-in-depth tracker. These include the U.S. Navy, which has used the device in a study of oversea flying performance in telemetry-tracked aircraft, and the Essex Corp., which has used the device in a study of overland flying and landing performance of telemetry-tracked aircraft. I understand that a simulator manufacturer (CAE), currently working on a project linked to Williams AFB, plans to further develop and use the technique for pilot assessment.

In brief, the rationale for the technique was the hypothesis that the visual system contains several, rather independent, functional subunits, including the "looming" subunit. We have previously reported evidence that the visual system contains a subunit that responds to line-of-sight motion (i.e. looming) virtually independently of visual parameters including trajectory, sideways motion, and contrast changes (Refs 66, 82).

Conventional eye-hand tracking tests have the subject track a target that moves in the frontal plane only, i.e. it does not move in depth. This conventional tracking test will not test visual responses to motion along the line of sight. Our test has subjects track a target whose size changes continuously and unpredictably and appears to move in depth. Our technique tests visual sensitivity to line-of-sight motion. A variation of the technique ("perturbed tracking") has the subject track the target's motion in depth while the target is given random sideways motion. If motion-in-depth tracking performance is unimpaired, this shows that visual sensitivity to the line-of-sight component motion is independent of trajectory and of simultaneous frontal plane motion caused e.g. by head vibration.

(ii) Fine spatial discriminations and visual contrast sensitivity

A current idea in visual science is that the eye breaks up spatial information (e.g. size and shape) into spatial frequency bands that separately es

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deal with fine detail, intermediate detail, and coarse detail. There is an indefinite number of such channels, each tuned to a fairly broad range of orientations. Because these spatial frequency and orientation bandwidths are broad, this analysis is crude. Consequently, it is difficult to understand how subjects are so acutely sensitive to differences in size and orientation.

We collected the first data on spatial frequency discrimination in a substantial group of control subjects (14-26 eyes in Ref 92). Previous data were for two subjects only (Campbell et al, 1970). The subject's task was to judge which of two sinewave gratings had the finer bars. Over a broad range it is not the absolute difference but the percentage difference in spatial frequency that determines threshold. Subjects can detect about 2% to 5% difference. Other workers have noted ripples in the curve (Hirsch & Hylton, 1982; Richter & Yager, 1984), but our spatial frequencies were not close enough to bring out that point. This finding agrees with Campbell, Jukes & Nachmias (1970).

How is size (or spatial frequency) discrimination related to spatial detection? How does discrimination relate to the channel model? We considered several possibilities, including the following: (a) the relative activity of many channels determines discrimination; (b) Watson and Robson's idea tht spatial frequency channels are "labelled", and the most active channels signal the target's spatial frequency.

Our rationale was this: if one channel has its sensitivity depressed by adaptation, then model (a) predicts that discrimination will be degraded, but at a different spatial frequency to the contrast sensitivity loss. Model (b) is inconsistent with this prediction. Our experiments rejected model (b) and supported model (a). Figure 1 shows that, in control subjects, adapting to a grating of 5 cycles/deg elevated contrast threshold at 5 cycles/deg as

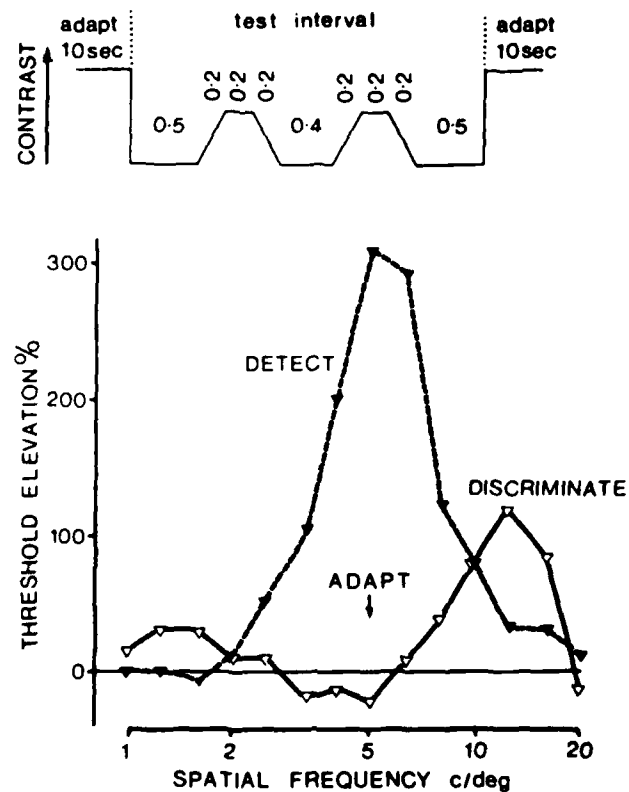


Fig. 1. Changes in contrast detection thresholds (dashed line) and in spatial-frequency discrimination thresholds (solid line) caused by inspecting a sine-wave grating of frequency of 5 c/deg. Subject DR.

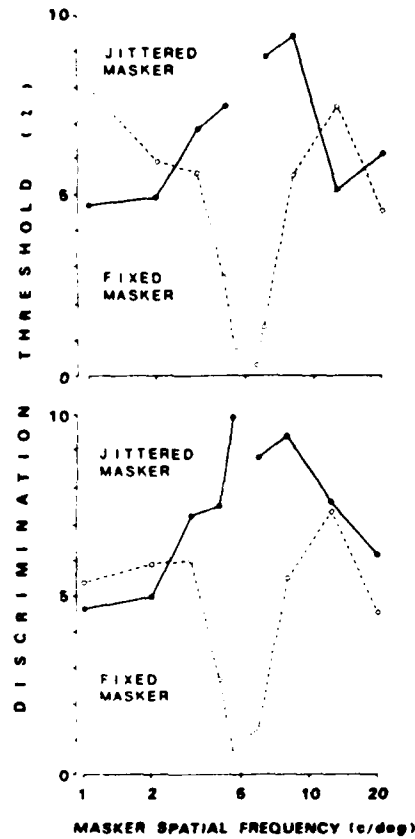


Figure 2. Masked spatial frequency discrimination thresholds (ordinates) for a vertical 5 cycle/deg test grating versus the spatial frequency of a vertical masker grating (abscissae). Broken lines (open symbols) are for a masker whose frequency was the same on every trial. Continuous lines (filled symbols) are for a masker whose frequency was slightly different on each trial (up to  $\pm 10\%$  difference). Data are shown for two subjects.

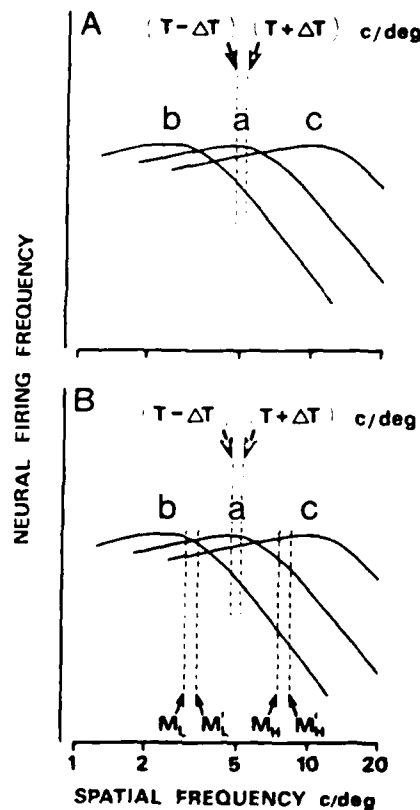


Figure 3. The continuous lines represent tuning curves of three neurons that are driven from the same retinal location. A - Opponent-size hypothesis of spatial frequency discrimination. Test grating frequency changes from  $(T - \Delta T)$  to  $(T + \Delta T)$  cycles/deg. A small change in the spatial frequency of the test grating produces little change in the firing of the most excited neuron (a), but a considerable change in the balance of activity between neurons (b) and (c), the greater contribution to this change in balance coming from (b). B - Opponent-size hypothesis of discrimination masking. Test grating frequency changes from  $(T - T)$  to  $(T + T)$  cycles/deg, and simultaneously the masker grating's frequency changes between  $M_L$  and  $M_L'$  or between  $M_H$  and  $M_H'$  cycles/deg. The balance between the excitations of neurons b and c depends on the random change in masker frequency as well as on the change in test frequency. Since the slope of neuron b is lower at 3 than at 8 cycles/deg, the effect of the 3 cycles/deg masker  $M_L$  is less than the effect of the 8 cycles/deg masker  $M_H$ .

expected, but also elevated discrimination threshold--not at 5 but at 12 cycles/deg (Ref 139). We proposed that spatial frequency discrimination is determined by size-opponent elements in the visual pathway. This hypothesis can also explain our finding that spatial frequency discrimination was not affected by randomly varying the contrast of successive gratings; the discrimination process does not confound frequency change with contrast change (Ref 139).

In a second study we measured the effect of masking upon spatial frequency and discrimination (Ref 152 and presented to OSA, San Diego, 1984). Although masked contrast detection thresholds were well known, masked discrimination thresholds had not been previously reported. Discrimination thresholds were measured by the standard temporal 2AFC procedure (method of constant stimuli), but a masker grating was superimposed on the test grating. With a constant frequency masker grating, subjects were able to use moiré pattern cues to frequency and achieved high discrimination (Fig 2, broken line). In order to deny the use of moiré cues we randomly changed the marker frequency between presentations (by  $\pm 10\%$ ). This procedure revealed that the masker grating produced an elevation of discrimination threshold that was greatest near the test frequency (Fig 2, continuous line). The area under the curve was a little greater above than below the test frequency. These discrimination changes are quite different from those produced by adaptation: discrimination threshold is not elevated at the adapting frequency, but the masking effect is large at the masker frequency; adaptation elevates thresholds above the adapting frequency while the minor skew shown by masked data is in the opposite direction.

Nevertheless, as shown in Fig 3, both masked and postadaptation discrimination can be accounted for by the same opponent-size model.

In a further study we investigated postadaptation orientation discrimination (Ref 150). Confirming previous reports we found that adapting to a vertical grating elevated contrast detection threshold for a vertical test grating, and this detection threshold elevation had a half bandwidth of about 8 deg (Fig 4, dotted line). Our new finding was that orientation discrimination thresholds were improved rather than degraded for vertical test gratings, while for gratings inclined at 10-20 deg from the vertical, discrimination was degraded though detection was little affected. These findings can be explained if orientation discrimination is determined by the relative activity of multiple channels, for example by opponent-orientation elements. This hypothesis can also explain our finding that changes in orientation were not confounded with simultaneous changes of contrast or spatial frequency.

An opponent model of discrimination and a line element model are formally rather similar. H. Wilson and I collaborated in an attempt to test his line element model. We carried out the experiment "blind"; I acquired data according to an agreed protocol, and he was required to predict the data after I had acquired it, but he did not know the data. Quantitative and qualitative agreement between prediction and data were good (Ref 152).

(iii) Spatial vision: extraction of figure from ground by motion

It is well known that some objects that cannot be seen in the absence of motion become visible when there is relative motion between the object and its background. A practical example is that grassy hillocks and ridges that cannot be seen from a hovering helicopter can become clearly visible when the helicopter is moving.

Figure 5 illustrates a laboratory version of such a target. These are photographs of a dot pattern on a CRT. A contains a camouflaged rectangle.

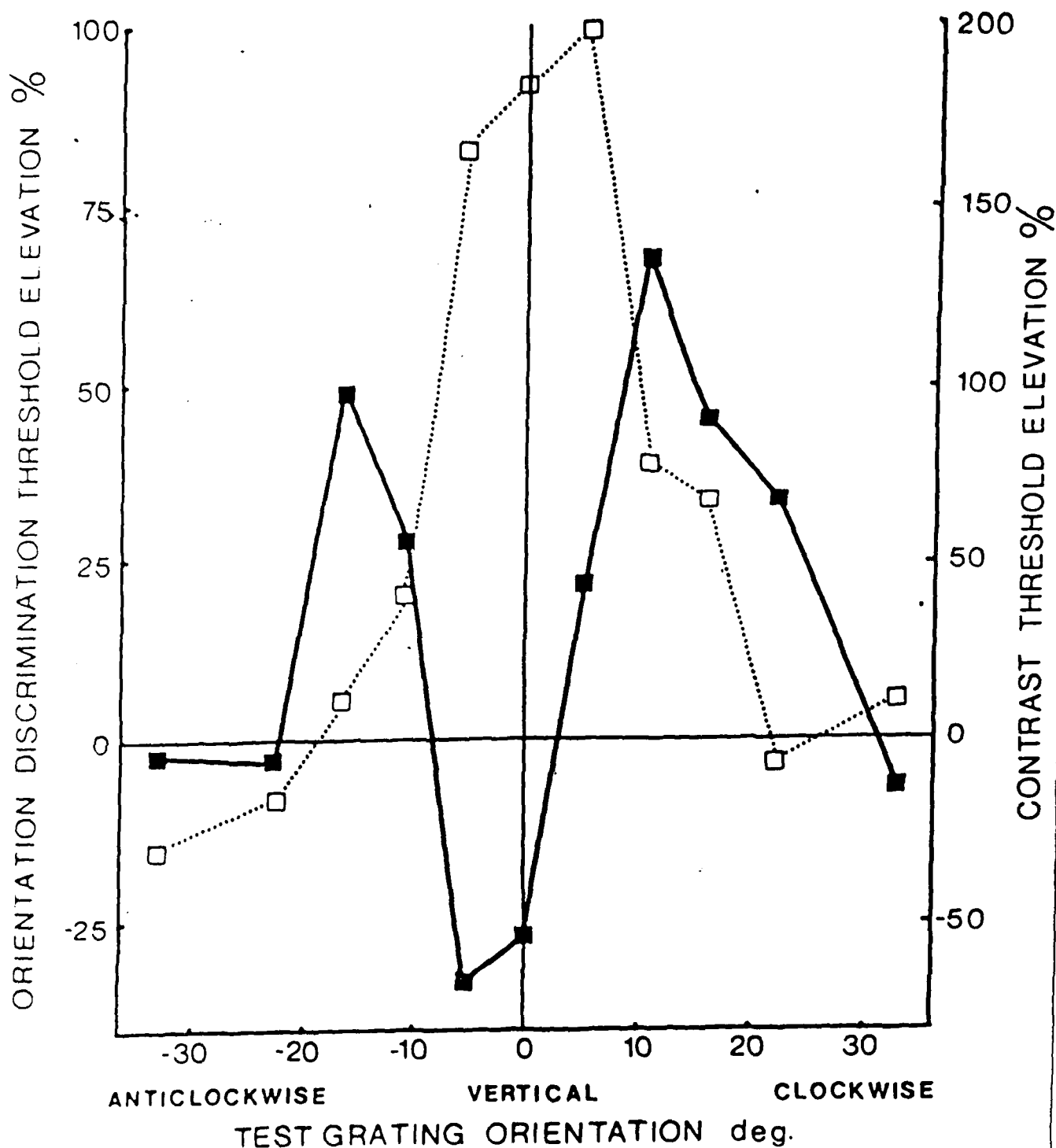


Figure 4. Postadaptation threshold elevations for orientation discrimination (continuous line) and for contrast detection (dotted line). The adapting grating was vertical (0 on abscissa).

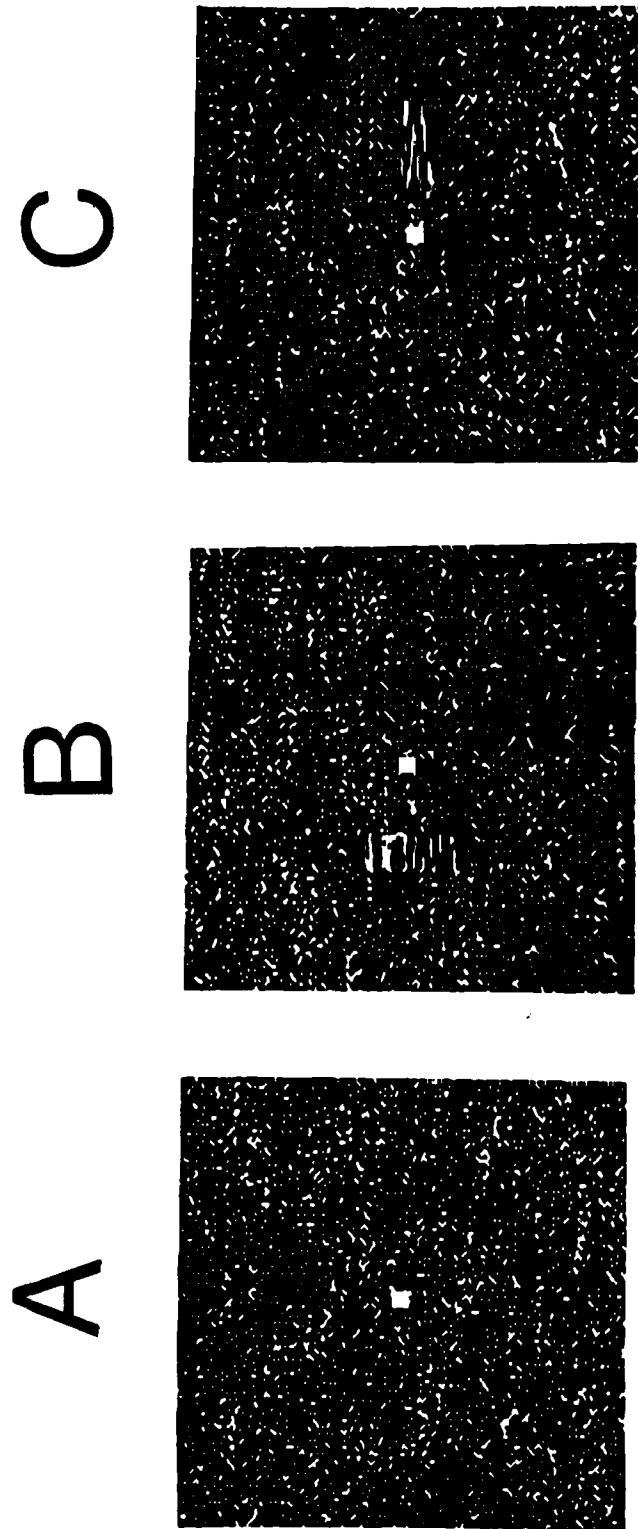


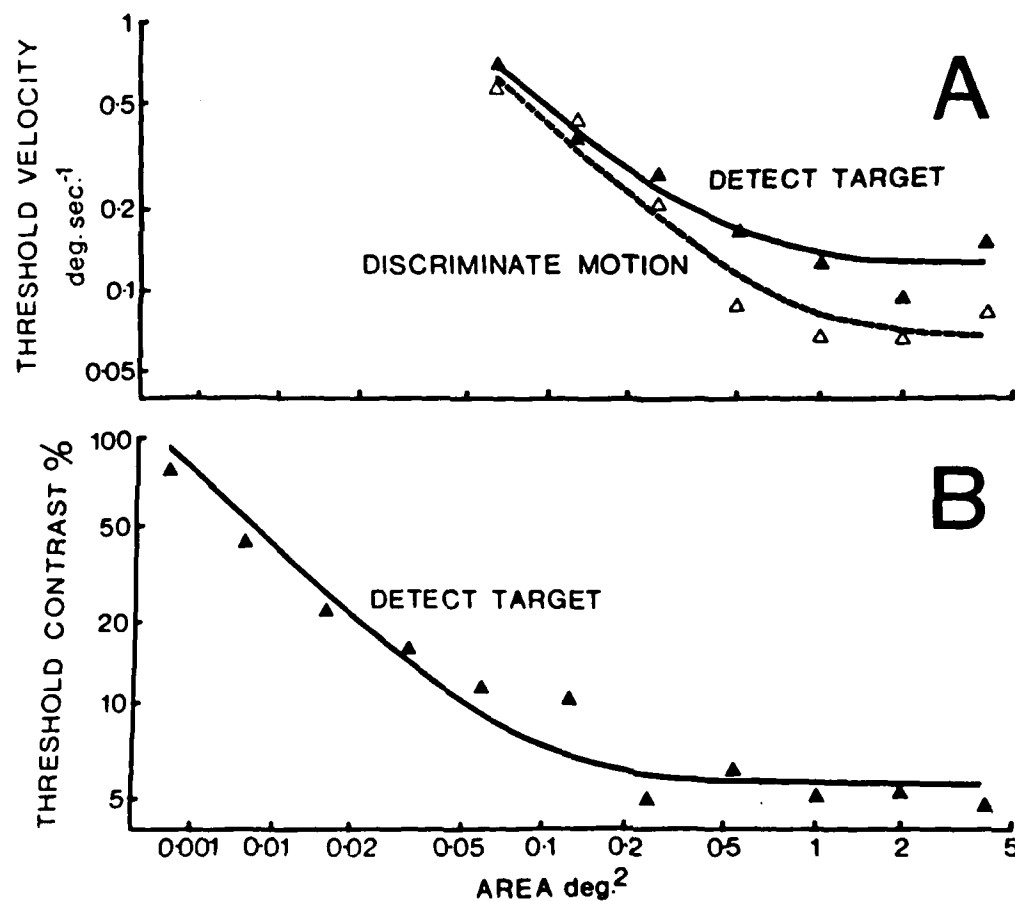
Figure 5 - Camouflaged target stimulus. A - The rectangular target is invisible in the absence of relative motion. B and C - The rectangular target's boundaries are defined by relative motion.

In **B** and **C** the dots within this rectangle move and the rectangle becomes visible (the moving dots appear as streaks in the two exposures). The boundaries or edges of the rectangle are made visible (i.e. the camouflage is broken) by motion: in the absence of motion the rectangle is invisible. Compare this with a conventional target. A conventional target's boundaries are brightness steps. Clearly, these are two quite different types of object. One is defined by motion steps, the other by brightness steps.

We, and others, have previously explored target visibility produced by abruptly displacing part of a dot pattern (Regan & Spekreijse, 1970; Julesz, 1971; Braddick, 1974; Baker & Braddick, 1981). Providing that the abrupt displacement does not exceed about 20 min arc and take longer than 100 msec, the "short range" process operates so that the target's camouflage is broken and it becomes visible. However, these previous studies did not use continuous motion, and thus confounded the effects of dot displacement and stimulus duration. Our study used continuous velocity and explored the effect of velocity on target visibility, looking at temporal and spatial summation in fovea and periphery (Ref 138).

Figures 6 and 7 compare target parafoveal detection thresholds for: (a) a dot target whose edges are defined by motion contrast, and (b) a conventional target whose edges are defined by luminance contrast. Figure 6 shows how target detection thresholds depend on stimulus area. The lines are theoretical fits assuming that receptive fields have gaussian sensitivity profiles. Receptive field area is about five times larger for targets whose boundaries are defined by motion contrast, the areas for camouflaged targets being about  $0.16 \text{ deg}^2$  in the parafovea.

Figure 7 shows how target detection threshold depends on presentation duration. The line in Fig 7B is a theoretical fit assuming a single stage



**Figure 6** - Effects of target area. A is for camouflaged targets whose boundaries were defined by relative motion, and B is for conventional targets whose boundaries were defined by luminance contrast. The curves in A and B are theoretical fits assuming a gaussian sensitivity profile for summation fields. Spatial summation area is about 5 times larger for targets defined by relative motion (A) than for targets defined by luminance contrast (B). Targets were square and presented for 150 msec.

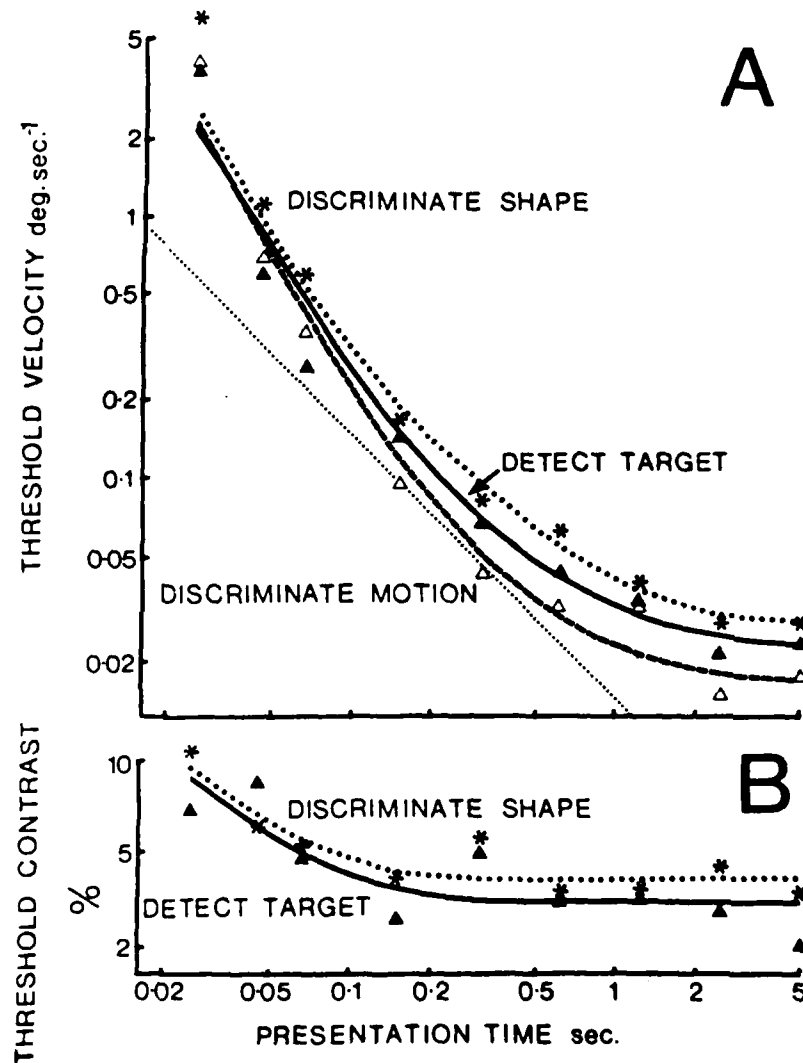


Figure 7 - Effect of presentation duration. A is for camouflaged targets whose boundaries were defined by relative motion, and B is for conventional targets whose boundaries were defined by luminance contrast. The dotted line in A plots a constant-displacement law, displacement being 1 min arc. The curves in B are theoretical fits assuming a single integration time constant  $\tau_1$ . The theoretical curves in A assume a two-stage temporal integration, the same time constant  $\tau_1$  being followed by a time constant  $\tau_2$  over 12 times larger. The rectangular targets were of constant shape ( $K = 2.8$ ) and 1 deg<sup>2</sup> area.

exponential integration process. The time constant is 60 msec, consistent with classical data. The theoretical curve fitting the new data in Fig 7A assumes a two-stage exponential integration process. The first stage has the same time constant as the luminance integration stage of Fig 7B. The second stage has a time constant of 750 msec. Thus, temporal integration extends over about 12 times longer duration for a target whose edges are defined by motion contrast than for a target whose edges are defined by luminance contrast.

Figure 8 shows how thresholds varied as a function of eccentricity for different target areas. Log threshold was linearly proportional to eccentricity between 0 deg and 32 deg eccentricity at least. The slope of the plot depended on target area, sensitivity to larger targets being less affected by eccentricity.

(iv) Judging the direction of motion in depth from looming information alone

Discriminating the directions of motion in depth. The direction of a target's motion in depth can be discriminated with a remarkable acuity of about 0.2 deg when viewing is binocular (Beverley & Regan, 1975). It has been proposed that this high acuity can be explained in terms of sensitivity to relative motion, in this case a velocity ratio. Because the two eyes are a few centimeters apart, the left and right eyes' images of an object moving in depth move with different velocities,  $V_D$  and  $V_S$  respectively. The ratio  $V_D/V_S$  is uniquely related to the direction of motion in depth. We reported psychophysical evidence that the human visual system contains elements tuned to the velocity ratio (Ref 34). In the experiment of Fig 9 the subject viewed two dot patterns, one with each eye. Each pattern oscillated from side to side at the same rate, but with different velocities. The subject's task was to set thresholds for just-visible motion in depth. Figure 9 shows threshold

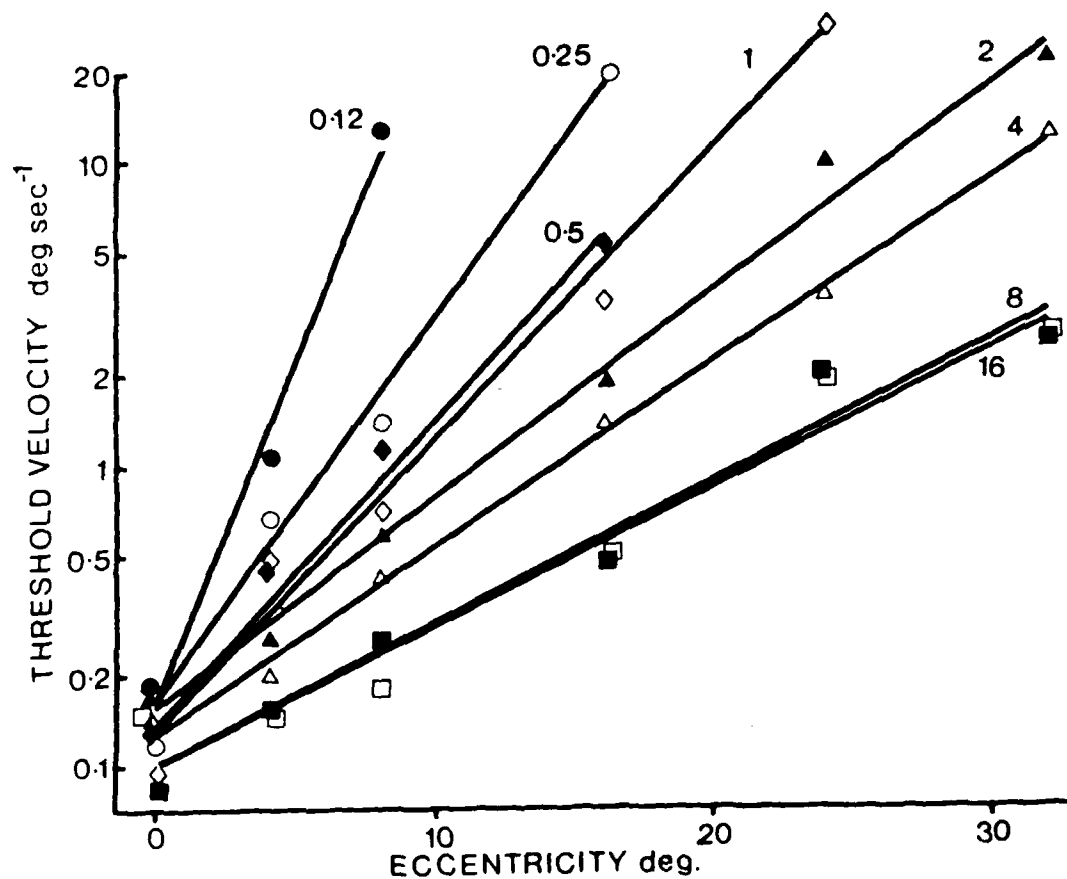


Figure 8 - Log detection threshold for camouflaged dot targets is proportional to eccentricity. The effect of eccentricity is less for larger targets.

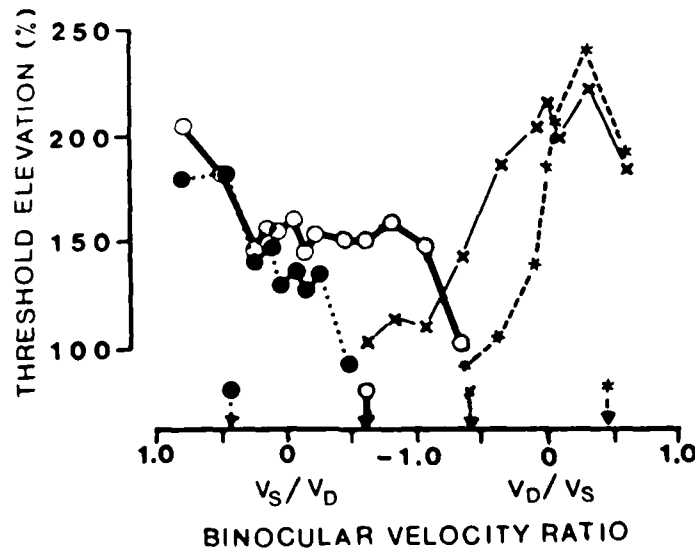


Figure 9. Thresholds for the detection of motion in depth were measured for different ratios of the left ( $V_D$ ) and right eye's ( $V_S$ ) retinal image velocities. Threshold elevations were plotted as ordinates versus the velocity ratio of the test oscillation after adapting to four different directions of motion in depth. A negative sign means that  $V_S$  and  $V_D$  are in opposite directions. Filled circles, fine continuous line - adapting ratios  $V_S/V_D = +0.5$  (trajectory to left of left eye). Open circles, heavy continuous line - adapting ratio  $V_S/V_D = +0.5$  (trajectory passes between eyes to left of centre). Crosses, fine continuous line - adapting ratio  $V_D/V_S = -0.5$  (trajectory passes between eyes to right of centre). Stars, broken line - adapting ratio  $V_D/V_S = +0.5$  (trajectory passes to right of right eye). Arrows mark the adapting stimulus ratios.

elevations caused by separately adapting to four different  $V_D/V_S$  ratios. The data can be understood if the visual system contains eight kinds of binocular element, each tuned to a different value of  $V_D/V_S$ , four preferring movement towards the head and four preferring movement away from the head. These elements are not arranged orthogonally. For the purpose of the following discussion, note that adapting to a direction inclined just to the left of the nose (open circles) gives a clearly different threshold elevation curve than adapting to a direction inclined just to the right of the nose (crosses), consistent with the idea that the two central elements sharply differentiate between trajectories to the left and right of the nose. By analogy with Hering's theory of color vision we suggested that, in binocular vision, directional discrimination is mediated by interaction between these overlapping elements, much as color discrimination is mediated by difference signals between the three color mechanisms (Ref 49). According to this suggestion, directional acuity would be determined, not by the bandwidths of these ratio-tuned binocular elements, but by the noise level of the elements.

Monocular discrimination of the direction of motion in depth is a different problem, but can be approached analogously to the binocular case. An object moving along an arbitrary trajectory is simultaneously changing size and moving in the frontal plane. Figure 10 illustrates how the ratio between the velocities of a square's vertical edges is related to its direction of motion. When the centre of the square moves directly through the eye, the speeds of the left and right edges are equal and opposite ( $V_L/V_R = -1.0$  in Fig 10A). When the square moves to the right as it comes towards the eye but still hits the eye, the left and right edges move in opposite directions with the left edge moving slower than the right ( $V_L/V_R = -0.5$  in Fig 10B). When the square's left edge just grazes the eye, the left edge appears stationary

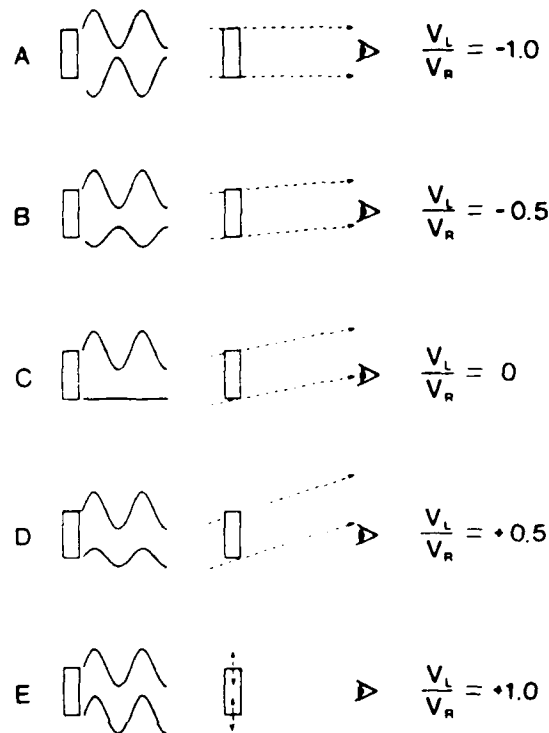


Figure 10. Monocular correlate of the direction of motion in depth. A-E show a square object oscillating along various directions of motion in depth with respect to the eye. F-J show the oscillations of the object's left and right edges seen by the eye.  $V_L$  and  $V_R$  are the instantaneous angular velocities of the left and right edges. A negative sign means that  $V_L$  and  $V_R$  are in opposite directions. When  $0 < (V_L/V_R) < 1.0$ , the square would pass to the right of the eye. When  $(V_L/V_R) = 0$  the left edge of the square would just graze the eye. When  $-1.0 < (V_L/V_R) < 0$  the square would hit the eye. Similar relations hold for  $(V_R/V_L)$ .

( $V_L/V_R = 0$  in Fig 10C). When the square passes to the right of the eye, the left and right edges move in the same direction, the left edge slower than the right ( $V_L/V_R = +0.5$  in Fig 10D), and when the square moves in the frontal plane, left and right edges move identically ( $V_L/V_R = +1.0$  in Fig 10E). Subjects are quite sensitive to differences in the  $V_L/V_R$ ; the trajectory  $V_L/V_R = 1.1$  is seen to be clearly tilted in depth compared with  $V_L/V_R = 1.0$ .

One possible explanation for monocular discrimination of the direction of motion in depth would be that the visual pathway contains several elements tuned either to different  $V_L/V_R$  ratios (Fig 10) or to different combinations of changing size and frontal plane motion. For example, one kind of element might prefer increasing size combined with rightward motion (stimulus A), while a second kind preferred increasing size combined with leftward motion (stimulus B). Discrimination would be determined by the relative activity of these notional elements. In order to test for the presence of such selective sensitivities, a monocular adaptation experiment was carried out whose rationale was analogous to the binocular experiments of Fig 9. In the monocular experiment, subjects set oscillation thresholds for stimuli A and B before and after adapting to stimulus A, and before and after adapting to stimulus B. Figure 11 plots postadaptation threshold elevations versus the  $V_L/V_R$  ratios of the 12 different test stimuli. Test and adapting squares were centrally viewed, 1.0 deg side length and of luminance  $12 \text{ cd/m}^2$  superimposed on a 10 deg x 10 deg background of luminance  $25 \text{ cd/m}^2$ . Each edge oscillated sinusoidally with a frequency of 1.0 Hz. The initial adaptation period was 15 min. The trial interval was 6 sec with 20 sec readapt between trials. Four different adapting stimuli were used: L12R6 inphase (filled circles, fine dotted line); L12R6 antiphase (open circles, heavy continuous line); L6R12 antiphase (crosses, fine continuous line); L6R12 inphase (stars, broken line),

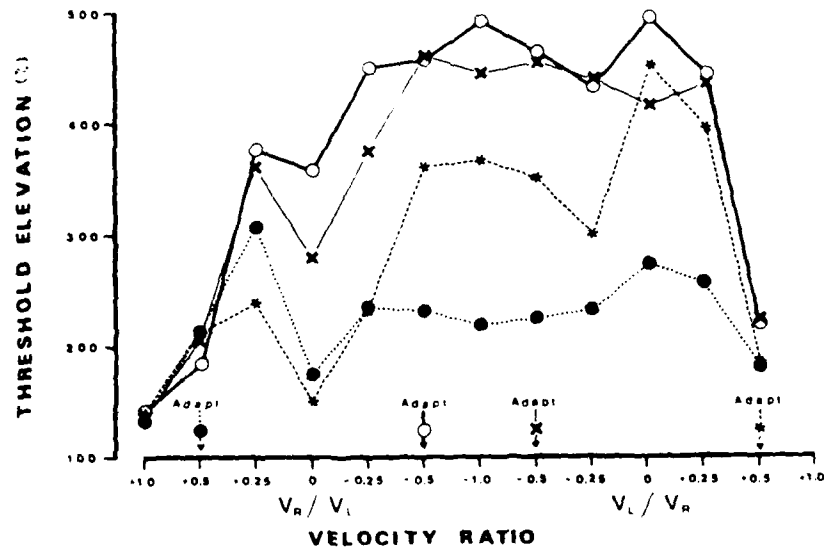


Figure 11. Monocular threshold elevations caused by adapting to different directions of motion in depth. Abscissae plot ratios between the velocities of the test square's left and right edges. The four curves are for the four adapting directions arrowed. Filled circles, fine dotted line - adapting ratio  $V_R/V_L = +0.5$  (trajectory to left of eye). Open circles, heavy continuous line - adapting ratio  $V_R/V_L = -0.5$  (trajectory passes through eye just left of centre). Crosses, fine continuous line - adapting ratio  $V_L/V_R = -0.5$  (trajectory passes through eye just right of centre). Stars, broken line - adapting ratio  $V_L/V_R = +0.5$  (trajectory to right of eye).

where L and R refer to the left and right edges and the numbers are oscillation amplitudes in minutes of arc.

Figure 11 clearly rejects the idea that threshold elevations were entirely determined by the oscillations of individual edges. For example, the two L12R6 adapting stimuli had identical oscillation amplitudes and velocities, but gave quite different threshold elevations (compare filled and open circles). These two adapting stimuli differed only in the phase relation between opposite edges. On the other hand, the Fig 11 monocular data differ from the Fig 9 binocular data in that adapting to trajectories inclined just to the left and right of centre did not produce clearly different elevation curves (compare open circles and crosses in Figs 9 and 11) so that, in contrast with the binocular findings, there was no evidence for elements that sharply distinguished between trajectories inclined slightly to the left and right of a collision course. The only evidence for a monocular element that preferred increasing size with rightward motion and decreasing size with leftward motion was the asymmetry of the Fig 11 curve marked by stars. There was no evidence for elements tuned to the converse  $V_L/V_R$  ratio (filled circles). Thus, the Fig 11 data can almost entirely be explained by assuming that, in contrast with the binocular analysis of motion in depth, monocular analysis is chiefly into orthogonal velocity components. These components comprise motion towards and away from the eye along the line of sight, and leftwards and rightwards in the frontal plane. [Different directions in the frontal plane would be dealt with by different frontal plane motion elements (Sekuler, Pantle & Levinson, 1978).] On the other hand, Fig 11 gives some suggestion that, in addition, there might be elements tuned to values of  $V_L/V_R$  other than +1.0 and -1.0.

(v) Correlation between visual test results and flying performance in  
simulators and telemetry-tracked high performance jet aircraft

Laboratory visual tests comprised a manual tracking task of frontal plane motion (TII), a manual tracking task of motion in depth (TAI), and a supra-threshold velocity discrimination task in which subjects viewed a radially-expanding flow pattern and were required to judge which of two rates of flow was the faster (FF). The airborne visual tests were carried out between two A4 aircraft flying towards each other from a range of about 25 miles. One was designated as attacker. In order to record visual acquisition distance the attacking aircraft was instructed to fire a simulated missile on first sighting the target aircraft. The target was instructed to turn sharply to left or right immediately on hearing the audible firing tone from the attacker aircraft. This turn was typically about 70 deg bank and 3G acceleration. The attacker was further instructed to call the direction immediately on being able to discriminate the direction of the target's turn. The attacker's ability to detect the direction of the target's turn was measured in two ways: first as the angular displacement of the target aircraft between the start of the target's turn and the attacker's correct call, and second as the distance between aircraft at the instant that the attacker gave his correct call. Flying performance was measured in a low-level bombing task (A4 aircraft) and in air-to-air combat (A4 versus F-14).

Tables 1 and 2 shows correlations between flying performance and the results of both laboratory and airborne visual tests. Flying performance was measured in air-to-air combat between A4 and F-14 aircraft. Results for both airborne vision tests correlated with combat success as measured by the win/loss ratio (i.e. number of hits on opponents versus number of hits received). Judging a leftward or rightward turn could involve the following

TABLE I. LOW-LEVEL FLYING TASK

Correlation between no-drop bombing accuracy and	r	p
FF	0.67	0.01
TP1	0.63	0.02
TH	0.52	0.05
Correlation between bombing accuracy (real bombs) and		
FF	0.71	0.01
TP1	0.57	0.04
Correlation between no drop-bombing accuracy and bombing accuracy (real bombs)		
	0.73	0.01

TABLE II. AIR-TO-AIR COMBAT

Correlations Between	Nonsmoking aircraft (N = 6)		Smoking aircraft (N = 8)	
	r	p	r	p
<i>Acquisition range</i>				
kills/engagement	0.80	0.03	0.69	0.01
died/engagement	-0.85	0.02	NS	—
win/loss ratio	0.74	0.05	NS	—
direction detect range	0.79	0.03	0.96	0.001
flow pattern threshold	-0.60	0.10	-0.61	0.02
<i>Direction detection range</i>				
died shot at	-0.77	0.04	NS	—
died engagement	-0.88	0.01	NS	—
win/loss ratio	0.79	0.03	NS	—
kills/shot	NS	—	0.65	0.04
angular deflection	-0.91	0.006	NS	—
<i>Angular deflection</i>				
shots engagement	-0.83	0.02	NS	—
shot at engagement	0.78	0.03	0.77	0.01
died engagement	0.69	0.06	0.79	0.009
win/loss	-0.85	0.02	NS	0.08
TH	NS	—	-0.71	0.02
TA1	0.80	0.03	NS	—
FF	NS	—	0.66	0.04
		p	POOLED r	
<i>Shots engagement</i>				
TA1		-0.67		0.01
TP1		-0.67		0.01

two factors: (a) Visual sensitivity to aspect, since the target aircraft assumed leftward or rightward bank when changing heading; (b) visual sensitivity to frontal plane motion. The angular deflection measure was intended to bring out sensitivity to frontal plane motion. On the other hand, the importance of aspect has been emphasized by Kennedy et al. (1982). In order to find whether sensitivity to aspect alone could explain our findings we carried out a laboratory experiment using a stationary three-dimensional model A4 aircraft whose aspect was varied by setting it at the angles of bank for a left or right turn. Subjects judged left and right bank at different viewing distance, and we plotted the percent correct judgments on probability paper (Fig 12). Subjects' discrimination of bank angle did not fall to 75% correct until the angular size of the model aircraft fell to 3.3 min arc (subject KB) or 3.8 min arc (subject RP) wingtip to wingtip. This corresponded to a viewing distance of 8226 meters (subject KB) or 7130 meters (subject RP) for a real A4 aircraft. Our Fig 12 data suggest that, providing the target aircraft's contrast is about 60% at 7300 m distance or a little less, pilots could judge a change of heading merely by detecting the angle of bank. The broken lines in Fig 12 show that reducing target contrast from 60% to 30% is equivalent to a scaling factor.

One uncertainty about our laboratory study is that visual conditions in the air and in the laboratory were, unavoidably, quite different. We tried to compare airborne distances with our laboratory data by normalizing relative to visual acquisition distance. Therefore, we measured visual acquisition distance in the laboratory. For the 30% contrast model, detection was 25% above chance (75% correct) when the model's angular size was 2 min arc (both subjects), i.e. at a little less than twice the range at which change of direction could be detected. For a contrast of 60%, detection was 25% above

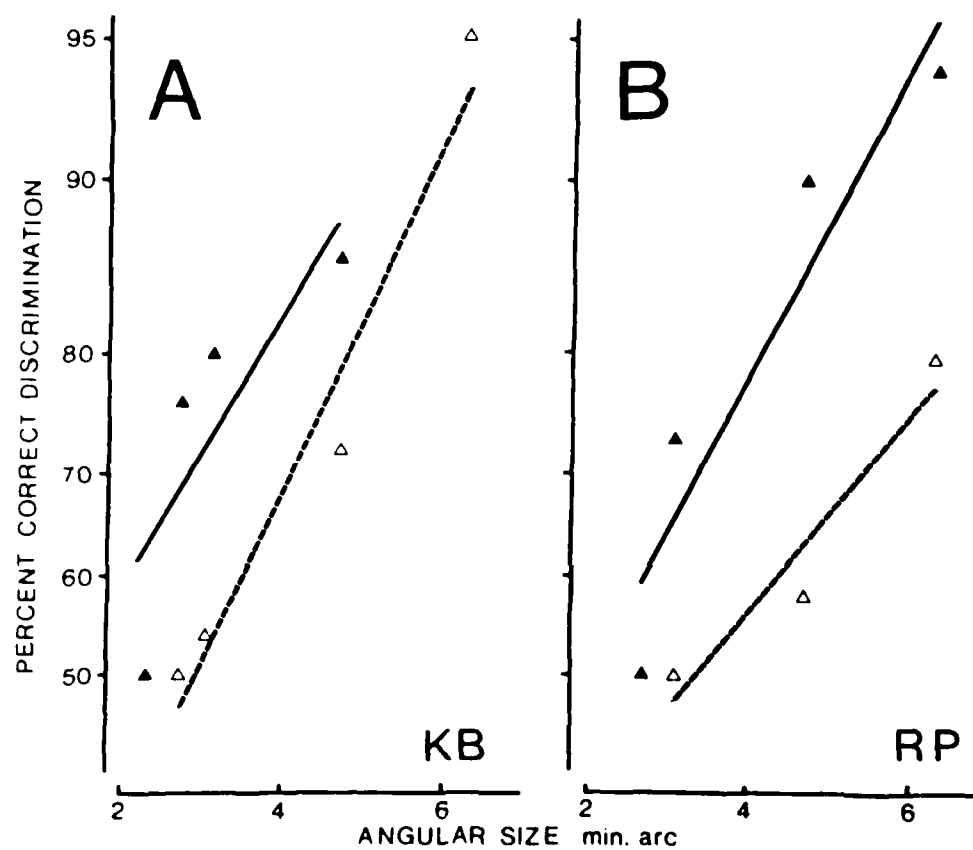


Figure 12 - Ordinates plot on a probability axis percent correct discriminations between leftward and rightward angles of bank of a model A4 aircraft. The angular sizes of the aircraft are plotted as abscissae. A and B show data for two subjects. Continuous lines are for an aircraft of 60% contrast, broken lines for 30% contrast.

chance when the angular size was about 1.8 min arc (subject RP) and 1.4 min arc (subject KB). This comparison, however, is likely to favor the laboratory data because of the lag while pilots made a motor response and because of the pilots' initial uncertainty as to the location of the adversary aircraft. Because laboratory subjects knew the model's location, because we used a 75% detection criterion (pilots would likely use a higher-certainty criterion), and because there was no atmospheric haze, laboratory acquisition distances are likely to be spuriously large. However, the roughly 1.6:1 to 1.9:1 ratio between the two laboratory measures compares with the roughly 1.6:1 ratio between mean visual acquisition distance for real aircraft and mean distance at which change in heading was detected. This suggests that aspect alone could account for discriminating change in heading in our airborne visual tests.

### References

- Baker, C.L. & Braddick, O.J. (1982) The basis of area and dot number effects in random dot motion perception. *Vision Res* 22, 1253-1259.
- Beverley, K.I. & Regan, D. (1975) The relation between discrimination and sensitivity in the perception of motion in depth. *J Physiol* 249, 387-398.
- Bodis-Wollner, I., Hendley, C.D., Mylin, L.H. & Thornton, J. (1979) Visual evoked potentials and the visuogram in multiple sclerosis. *Ann Neurol* 5, 40-47.
- Braddick, O.J. (1974) A short-range process in apparent motion. *Vision Res* 14, 519-527.
- Braddick, O., Campbell, F.W. & Atkinson, J. (1978) Channels in vision: Basic aspects. In R. Held, H.W. Leibowitz and H.-L. Teuber (Eds.), Handbook of Sensory Physiology (Vol. 8). New York, Springer.
- Campbell, F.W., Nachmias, J. & Jukes, J. (1970) Spatial frequency discrimination in human vision. *J Opt Soc Am* 60, 555-559.
- Hirsch, J. & Hylton, R. (1982) Limits of spatial frequency discrimination as evidence of neural interpolation. *J Opt Soc Am* 72, 1367-1374.

- Julesz, B. (1971) Foundations of Cyclopean Perception. Chicago, Univ. of Chicago Press.
- Kennedy, R.S., Collyer, S.C., May, J.G. & Dunlap, W.P. (1982) Visual simulation requirements for aircraft aspect recognition at real world distances. Paper presented at Human Factors meeting, October.
- Lee, R. (1976) A theory of visual control of braking based on time to collision. *Perception* 15, 437-459.
- Ogle, K.N. (1970) Researches in Binocular Vision. Philadelphia, Saunders.
- Poser, C.M. (1984) The Diagnosis of Multiple Sclerosis. New York, Thieme-Stratton.
- Regan, D. & Spekreijse, H. (1970) Electrophysiological correlate of binocular depth perception in man. *Nature* 225, 92-94.
- Reichardt, W., Poggio, T. & Hausen, K. (1983) Figure-ground discrimination by relative movement. *Biol Cybern* 46, 1.
- Richards, W. (1970) Stereopsis and stereoblindness. *Exp Brain Res* 10, 380-388.
- Richards, W. (1979) Quantifying sensory channels: Generalization colorimetry to orientation and texture, touch, and tones. *Sensory Processes* 3, 207-229.
- Richter, E.S. & Yager, D. (1984) Spatial-frequency difference thresholds for central and peripheral viewing. *J Opt Soc Am A* 1, 1136-1139.
- Sekuler, R., Pantle, A. & Levinson, E. (1978) Physiological basis of motion perception. In Handbook of Sensory Physiology, Vol 8. New York, Springer.
- Wheatstone, C. (1838) Contributions to the physiology of vision. I. *Phil Trans R Soc* 13, 371-394.
- Zimmern, R.C., Campbell, F.W. & Wilkinson, R. S. (1979) Subtle disturbances of vision after optic neuritis. *J Neurol Neurosurg Psychiat* 42, 407-412.

## 2c. PUBLICATIONS

### Books

1. Regan D. Evoked potentials in psychology, sensory physiology and clinical medicine. London: Chapman & Hall; New York: Wiley, 1972. 328 pp. Rpt. 1975.
2. Regan D. The visual perception of motion. Oxford Psychology Series. Oxford University Press, in preparation.

### Papers

1. Regan D. Some characteristics of average steady-state and transient responses evoked by modulated light. Electroenceph clin Neurophysiol, 1966, 20, 238-48.
2. Regan D. An apparatus for the correlation of evoked potentials and repetitive stimuli. Med Biol Engng, 1966, 4, 168-77.
3. Regan D. An effect of stimulus colour on average steady-state potentials evoked in man. Nature, 1966, 210, 1056-7.
4. Regan D. A high frequency mechanism which underlies visual evoked potentials. Electroenceph clin Neurophysiol, 1968, 25, 237-9.
5. Regan D. Chromatic adaptation and steady-state evoked potentials. Vision Res, 1968, 8, 149-58.
6. Regan D. Evoked potentials and sensation. Perception & Psychophysics, 1968, 4, 347-50.
7. Regan D. Evoked potentials and colour vision. 7th ISCERG Symp., Istanbul (1969), publ. by Univ. of Istanbul (1971), pp 37-50.
8. Regan D. Chapters 3 & 4 in D. M. MacKay (Ed.), Evoked potentials as indicators of sensory information processing. Neurosci Res Bull, 1969, 7, No. 3.
9. Regan D. & Heron J.R. Clinical investigation of lesions of the visual pathway: a new objective technique. J Neurol Neurosurg Psychiat, 1969, 32, 479-83.
10. Tweel L.H. van der, Regan D. & Spekreijse H. Some aspects of potentials evoked by changes in spatial brightness contrast. 7th ISCERG Symp., Istanbul (1969), pub. by Univ of Istanbul (1971), pp 1-11.
11. Regan D. Evoked potential and psychophysical correlates of changes in stimulus colour and intensity. Vision Res, 1970, 10, 163-78.
12. Regan D. Objective method of measuring the relative spectral luminosity curve in man. J Opt Soc Am, 1970, 60, 856-9.
13. Regan D. & Heron J.R. Simultaneous recording of visual evoked potentials from the left and right hemispheres in migraine. In A.L. Cochrane (Ed.), Background to migraine. London: Heinemann, 1970, pp 66-77.

14. Regan D. & Cartwright R.F. A method of measuring the potentials evoked by simultaneous stimulation of different retinal regions. Electroenceph clin Neurophysiol, 1970, 28, 314-19.
15. Regan D. & Spekreijse H. Electrophysiological correlate of binocular depth perception in man. Nature, 1970, 255, 92-4.
16. Regan D. & Sperling H.G. A method of evoking contour-specific scalp potentials by chromatic checkerboard patterns. Vision Res, 1971, 11, 173-6.
17. Regan D. & Tyler C.W. Wavelength-modulated light generator. Vision Res, 1971, 11, 43-56.
18. Regan D. & Tyler C.W. Some dynamic features of colour vision. Vision Res, 1971, 11, 1307-24.
19. Regan D. & Tyler C.W. Temporal summation and its limit for wavelength changes: an analog of Bloch's law for color vision. J Opt Soc Am, 1971, 61, 1414-21.
20. Regan D. & Richards W. Independence of evoked potentials and apparent size. Vision Res, 1971, 11, 679-84.
21. Regan D. Evoked potentials to changes in the chromatic contrast and luminance contrast of checkerboard stimulus patterns. In G.B. Arden (Ed.), The visual system. New York: Plenum, 1972.
22. Regan D. Evoked potentials to changes in chromatic contrast. Proc. GAIN Symp. on EPs to spatial contrast. Trace, 1972, 6, 20-8.
23. Regan D. Cortical evoked potentials. Adv Behav Biol, 1972, 5, 177-92.
24. Spekreijse H., van der Tweel L.H. & Regan D. Interocular sustained suppression: correlations with evoked potential amplitude and distribution. Vision Res, 1972, 12, 521-6.
25. Milner B.A., Regan D. & Heron J.R. Theoretical models of the generation of steady-state evoked potentials, their relation to neuroanatomy and their relevance to certain clinical problems. Advances Med & Biol, 1972, 24, 157-69.
26. Regan D. Parallel and sequential processing of visual information in man: investigation by evoked potential recording. In Photophysiology, Vol 8. New York: Academic, 1973, pp 185-208.
27. Regan D. An evoked potential correlate of colour: evoked potential findings and single-cell speculations. Vision Res, 1973, 13, 1933-41.
28. Regan D. Evoked potentials specific to spatial patterns of luminance and colour. Vision Res, 1973, 13, 2381-2402.
29. Regan D. Rapid objective refraction using evoked brain potentials. Invest Ophthalmol, 1973, 12, 669-79.

30. Regan D. & Richards W. Brightness contrast and evoked potentials. J Opt Soc Am, 1973, '63, 606-11.
31. Regan D. & Beverley K.I. Disparity detectors in human depth perception: evidence for directional selectivity. Science, 1973, 18, 877-9.
32. Regan D. & Beverley K.I. Some dynamic features of depth perception. Vision Res, 1973, 13, 2369-79.
33. Regan D. & Beverley K.I. The dissociation of sideways movements from movements in depth: psychophysics. Vision Res, 1973, 13, 2403-15.
34. Beverley K.I. & Regan D. Evidence for the existence of neural mechanisms selectively sensitive to the direction of movement in space. J Physiol, 1973, 235, 17-29.
- 34a. Beverley K.I. & Regan D. Selective adaptation in stereoscopic depth perception. J Physiol, 1973, 232, 40-41P.
35. Regan D. & Beverley K.I. Relation between the magnitude of flicker sensation and evoked potential amplitude in man. Perception, 1973, 2, 61-5.
36. Regan D. & Beverley K.I. Electrophysiological evidence for the existence of neurones sensitive to the direction of depth movement. Nature, 1973, 246, 504-6.
37. Richards W. & Regan D. A stereo field map with implications for disparity processing. Invest Ophthalmol, 1973, 12, 904-9.
38. Cartwright R.F. & Regan D. Semi-automatic, multi-channel Fourier analyser for evoked potential analysis. Electroenceph clin Neurophysiol, 1974, 36, 547-50.
39. Regan D. Electrophysiological evidence for colour channels in human pattern vision. Nature, 1974, 250, 437-9.
40. Regan D. & Spekreijse H. Evoked potential indications of colour blindness. Vision Res, 1974, 14, 89-95.
41. Heron J.R., Regan D. & Milner B.A. Delay in visual perception in unilateral optic atrophy after retrobulbar neuritis. Brain, 1974, 97, 69-78.
42. Beverley K.I. & Regan D. Temporal integration of disparity information in stereoscopic perception. Exp Brain Res, 1974, 19, 228-32.
43. Beverley K.I. & Regan D. Visual sensitivity to disparity pulses: evidence for directional selectivity. Vision Res, 1974, 14, 357-61.
44. Regan D. Visually evoked potential methods with clinical applications. Proc. 11th ISCERG Symp., Bad Neuheim (1973). Docum Ophthalm, Series 4, 1974, 285-301.
45. Milner B.A., Regan D. & Heron J.R. Differential diagnosis of multiple sclerosis by visual evoked potential recording. Brain, 1974, 97, 755-72.

46. Regan D. Colour coding of pattern responses in man investigated by evoked potential feedback and direct plot techniques. Vision Res, 1975, 15, 175-83.
47. Heron J.R., Milner B.A. & Regan D. Measurement of acuity variations within the central visual field caused by neurological lesions. J Neurol Neurosurg Psychiat, 1975, 38, 356-62.
48. Regan D., Schellart N.A.M., Spekreijse H. & van den Berg T.J.T.P. Photometry in goldfish by electrophysiological recording. Vision Res, 1975, 15, 799-807.
49. Beverley K.I. & Regan D. The relation between discrimination and sensitivity in the perception of motion in depth. J Physiol, 1975, 249, 387-98.
50. Regan D. Recent advances in electrical recording from the human brain. Nature (review article), 1975, 253, 401-7.
51. Regan D., Milner B.A. & Heron J.R. Delayed visual perception and delayed visual evoked potentials in the spinal form of multiple sclerosis and in retrobulbar neuritis. Brain, 1976, 99, 43-66.
52. Regan D., Varney P., Purdy J. & Kraty N. Visual field analyser: assessment of delay and temporal resolution of vision. Med & Biol Engng, 1976, 14, 8-14.
53. Regan D. Latencies of evoked potentials to flicker and to pattern speedily estimated by simultaneous stimulation method. Elelctroenceph clin Neurophysiol, 1976, 40, 654-60.
54. Galvin R.J., Regan D. & Heron J.R. A possible means of monitoring the progress of demyelination in multiple sclerosis: effect of body temperature on visual perception of double light flashes. J Neurol Neurosurg Psychiat, 1976, 39, 861-5.
55. Galvin R.J., Regan D. & Heron J.R. Impaired temporal resolution of vision after acute retrobulbar neuritis. Brain, 1976, 99, 255-68.
56. Regan D. Fourier analysis of evoked potentials: some methods based on Fourier analysis. In J.E. Desmedt (Ed.), Visual evoked potentials in man: new developments. Oxford: Oxford Univ. Press, 1977, pp 110-7.
57. Regan D. Rapid methods for refracting the eye and for assessing visual acuity in amblyopia, using steady-state visual evoked potentials. In J.E. Desmedt (Ed.), Visual evoked potentials in man: new developments. Oxford: Oxford Univ. Press, 1977, pp 418-26.
58. Regan D. Evoked potential indications of the processing of pattern, colour, and depth information. In J.E. Desmedt (Ed.), Visual evoked potentials in man: new developments. Oxford: Oxford Univ. Press, 1977, pp 234-49.
59. Regan D., Milner B.A. & Heron J.R. Slowing of visual signals in multiple sclerosis, measured psychophysically and by steady-state evoked potentials.

- In J.E. Desmedt (Ed.), Visual evoked potentials in man: new developments. Oxford: Oxford Univ. Press, 1977, pp 461-9.
60. Regan D. Speedy assessment of visual acuity in amblyopia by the evoked potential method. Ophthalmologica, 1977, 175, 159-64.
  61. Regan D. & Spekreijse H. Auditory-visual interactions and the correspondence between perceived auditory space and perceived visual space. Perception, 1977, 6, 133-8.
  62. Galvin R.J., Heron J.R. & Regan D. Subclinical optic neuropathy in multiple sclerosis. Arch Neurol, 1977, 34, 666-70.
  63. Regan D. Steady state evoked potentials. Proc. Symp. Electrophysiological Techniques in Man. J Opt Soc Am, 1977, 67, 1475-89.
  64. Regan D. & Milner B.A. Objective perimetry by evoked potential recording: limitations. Electroenceph clin Neurophysiol, 1978, 44, 393-7.
  65. Regan D., Silver R. & Murray T.J. Visual acuity and contrast sensitivity in multiple sclerosis: hidden visual loss. Brain, 1977, 100, 563-79.
  66. Regan D. & Beverley K.I. Looming detectors in the human visual pathway. Vision Res, 1978, 18, 415-21.
  67. Cynader M. & Regan D. Neurones in cat parastriate cortex sensitive to the direction of motion in three-dimensional space. J Physiol, 1978, 274, 549-69.
  68. Regan D. & Beverley K.I. Illusory motion in depth: aftereffect of adaptation to changing size. Vision Res, 1978, 18, 209-12.
  69. Hillyard S.A., Picton T.W. & Regan D. Sensation, perception and attention: analysis using ERPs. In E. Callaway, P. Tueting & S.H. Koslow (Eds.), Event-related brain potentials in man. New York: Academic, 1978, pp 223-321.
  70. Regan D. Assessment of visual acuity by evoked potential recording: ambiguity caused by temporal dependence of spatial frequency selectivity. Vision Res, 1978, 18, 439-45.
  71. Regan D., Murray T.J. & Silver R. Effect of body temperature on visual evoked potential delay and visual perception in multiple sclerosis. J Neurol Neurosurg Psychiat, 1977, 40, 1083-191.
  72. Arden G.B., Bodis-Wollner I., Halliday A.M., Jeffreys A., Kulikowski J.J., Spekreijse H. & Regan D. Methodology of patterned visual stimulation. In J.E. Desmedt (Ed.), Visual evoked potentials in man: new developments. Oxford: Oxford Univ. Press, 1977, pp. 3-15.
  73. Regan D. Investigations of normal and defective colour vision by evoked potential recording. Mod Probl Ophthal, 1978, 19, 19-28.
  74. Regan D. Visual evoked potentials and visual perception in multiple

- sclerosis. Proc San Diego biomed symp, Vol 16. New York: Academic, 1977, pp 87-95.
75. Regan D. New methods for neurological assessment: overview. Proc San Diego biomed symp, Vol 16. New York: Academic, 1977, pp 55-62.
  76. Regan D., Beverley K.I. & Cynader M. Stereoscopic depth channels for position and for motion. In S.J. Cool & E.L. Smith (Eds.), Frontiers in visual science. New York: Springer, 1978, pp 351-72.
  77. Regan D. Evoked potentials in basic and clinical research. In A. Remond (Ed.), EEG informatics: a didactic review of methods and applications of EEG data processing. Amsterdam: Elsevier, 1977, pp 319-46.
  78. Regan D. Colour and contrast. In H. Spekreijse & L.H. van der Tweel (Eds.), Spatial contrast: report of a workshop. Pub. for Netherlands Royal Academy of Sciences. Amsterdam: North-Holland, 1977, pp 75-9.
  79. Regan D., Beverley K.I. & Cynader M. Stereoscopic subsystems for position in depth and for motion in depth. Proc R Soc Lond B, 1979, 204, 485-501.
  80. Regan D. & Tansley B.W. Selective adaptation to frequency-modulated tones: evidence for an information-processing channel selectively sensitive to frequency changes. J Acoust Soc Am, 1979, 65, 1249-57.
  81. Regan D. & Beverley K.I. Visually-guided locomotion: psychophysical evidence for a neural mechanism sensitive to flow patterns. Science, 1979, 205, 311-3.
  82. Beverley K.I. & Regan D. Separable aftereffects of changing-size and motion-in-depth: different neural mechanisms? Vision Res, 1979, 19, 727-32.
  83. Beverley K.I. & Regan D. Visual perception of changing size: the effect of object size. Vision Res, 1979, 19, 1093-1104.
  84. Regan D. & Cynader M. Neurons in area 18 of cat visual cortex selectively sensitive to changing size: nonlinear interactions between responses to two edges. Vision Res, 1979, 19, 699-711.
  85. Regan D. New visual tests in multiple sclerosis. In H. S. Thompson (Ed.), Topics in neuro-ophthalmology. Baltimore: Williams & Wilkins, 1980, pp 219-42.
  86. Regan D. & Beverley K.I. Binocular and monocular stimuli for motion-in-depth: changing-disparity and changing-size inputs feed the same motion-in-depth stage. Vision Res, 1979, 19, 1331-42.
  87. Regan D., Beverley K.I. & Cynader M. The visual perception of motion in depth. Sci Am, 1979, 241, 136-51.
  88. Regan D. Detection and quantification of neuroophthalmological abnormalities using psychophysical measures of visual delay and temporal resolution. In S. Sokol (Ed.), Electrophysiology and psychophysics: their use in ophthalmic diagnosis. Intl Ophthal Clinics. Boston: Little, Brown,

1980, pp 185-204.

89. Regan D. Visual psychophysical tests in multiple sclerosis as an aid to diagnosis, localization of pathology, and assessment of experimental therapy. In Clinical applications of visual psychophysics (Proc NAS/NRC Symp). New York: Cambridge Univ. Press, 1981.
90. Tansley B.W., Regan D. & Suffield J.B. Measurement of the sensitivities of information processing channels for frequency change and for amplitude change by a titration method. Can J Psychol, 1982, 36, 723-30.
91. Beverley K.I. & Regan D. Visual sensitivity to the shape and size of a moving object: implications for models of object perception. Perception, 1980, 9, 151-60.
92. Regan D., Whitlock J., Murray T.J. & Beverley K.I. Orientation-specific losses of contrast sensitivity in multiple sclerosis. Invest Ophthalmol Vis Sci, 1980, 19, 324-8.
93. Regan D. & Beverley K.I. Visual responses to changing size and to sideways motion for different directions of motion in depth: linearization of visual responses. J Opt Soc Am, 1980, 11, 1289-96.
94. Regan D. Control system and physiological monitoring applications of steady-state evoked potentials. In F.E. Gomer (Ed.), Biocybernetic applications for military systems. DARPA Conf, Chicago, 1978. St. Louis: McDonnell-Douglas. Report MDC E2191, 1980, pp 175-202.
95. Tansley B.W. & Regan D. Separate auditory channels for unidirectional frequency modulation and unidirectional amplitude modulation. Sensory Processes, 1979, 3, 132-40.
96. Regan D. & Beverley K.I. Motion sensitivity measured by a psychophysical linearizing technique. J Opt Soc Am, 1981, 71, 958-65.
97. Regan D. Electrical responses evoked from the human brain. Sci Am, 1979, 241, 134-46.
98. Beverley K.I. & Regan D. Device for measuring the precision of eye-hand coordination when tracking changing size. Aviat Space Environ Med, 1980, 51, 688-93.
99. Raymond J., Regan D. & Murray T.J. Abnormal adaptation of visual contrast sensitivity in multiple sclerosis patients. Can J Neurol Sci, 1981, 8, 221-34.
100. Noseworthy J., Miller J., Murray T.J. & Regan D. Auditory brainstem responses in postconcussion syndrome. Arch Neurol, 1981, 38, 275-8.
101. Regan D., Raymond J., Ginsburg A. & Murray T.J. Contrast sensitivity, visual acuity and the discrimination of Snellen letters in multiple sclerosis. Brain, 1981, 104, 333-50.
102. Regan D. Speedy evoked potential methods for assessing vision in normal and

- amblyopic eyes: pros and cons. Vision Res, 1980, 20, 265-9.
103. Petersik J.T., Beverley K.I. & Regan D. Contrast sensitivity of the changing-size channel. Vision Res, 1981, 21, 829-32.
104. Regan D. Chapters 11 & 12 in E. Donchin (Ed.), Cognitive psychology. In press.
105. Beverley K.I. & Regan D. Temporal selectivity of changing-size channels. J Opt Soc Am, 1980, 11, 1375-7.
106. Beverley K.I. & Regan D. Adaptation to incomplete flow patterns: no evidence for "filling-in" the perception of flow patterns. Perception, 1982, 11, 275-8.
107. Regan D. Evoked potential studies of visual perception. Can J Psychol, 1981, 35, 77-112.
108. Cynader M. & Regan D. Neurons in cat visual cortex tuned to the direction of motion in depth: effect of positional disparity. Vision Res, 1982, 22, 967-82.
109. Regan D. & Cynader M. Neurons in cat visual cortex tuned to the direction of motion in depth: effect of stimulus speed. Invest Ophthalmol Vis Sci, 1982, 22, 535-50.
110. Regan D. Electrophysiology and psychophysics of motion in depth. Proc 18th ISERG Symp, Amsterdam, 1981. Docum Ophthal, Proc Series, 1981, 27, 271-81.
111. Regan D., Regal D.M. & Tibbles J.A.R. Evoked potentials during recovery from blindness recorded serially from an infant and his normally sighted twin. Electroenceph clin Neurophysiol, 1982, 54, 465-8.
112. Regan D. Visual information channeling in normal and disordered vision. Psych Rev, 1982, 89, 407-44.
113. Regan D. Psychophysical tests of vision and hearing in patients with multiple sclerosis. In S.G. Waxman & J.M. Ritchie (Eds.), Demyelinating disease: Basic and clinical electrophysiology. Proc Vail Conf MS Soc of USA. New York: Raven, 1981, pp 217-37.
114. Kruk R., Regan D., Beverley K.I. & Longridge T. Correlations between visual test results and flying performance on the Advanced Simulator for Pilot Training (ASPT). Aviat Space Environ Med, 1981, 52, 455-60.
115. Quine D.B., Regan D. & Murray T.J. Delayed auditory tone perception in multiple sclerosis. Can J Neurol Sci, 1983, 10, 183-6.
116. Quine D.B., Regan D., Beverley K.I. & Murray T.J. Patients with multiple sclerosis experience hearing loss specifically for shifts of tone frequency. Arch Neurol, 1984, 41, 506-8.
117. Regan D., Kruk R., Beverley K.I. & Longridge T. The relevance of the channel theory of vision for the design of simulator imagery. Proc Image II

- Conf, Arizona, 1981, pp 307-44.
118. Regan D. Comparison of transient and steady-state methods. Proc NY Acad Sci, 1982, 388, 46-71.
  119. Regan D. Binocular vision. In Encyclopaedia of Physics. Pergamon, in press.
  120. Regan D. & Beverley K.I. How do we avoid confounding the direction we are looking with the direction we are moving? Science, 1982, 215, 194-6.
  121. Kaufman L. & Regan D. Visual perception of complex motion. In Handbook of vision, in press.
  122. Regan D. Human visual evoked potentials. In T. Picton (Ed.), Handbook of electrophysiology: Human event-related potentials. Amsterdam: Elsevier, in press.
  123. Kruk R., Regan D., Beverley K.I. & Longridge T. Flying performance on the Advanced Simulator for Pilot Training and laboratory tests of vision. Human Factors, 1983, 25, 457-66.
  124. Regan D. Visual psychophysical tests in demyelinating disease. Bull Soc Belge Ophtal, 1983, 208-I, 303-21.
  125. Regan D. & Beverley K.I. Visual fields described by contrast sensitivity, by acuity and by relative sensitivity to different orientations. Invest Ophthalmol Vis Sci, 1983, 24, 754-9.
  126. Beverley K.I. & Regan D. Texture changes versus size changes as stimuli for motion in depth. Vision Res, 1983, 23, 1387-1400.
  127. Regan D. & Beverley K.I. Psychophysics of visual flow patterns and motion in depth. In L. Spillmann & B.R. Wooten (Eds.), Sensory experience, adaptation and perception. Hillsdale, NJ: Erlbaum, 1984, 215-40.
  128. Regan D., Bartol S., Murray T.J. & Beverley K.I. Spatial frequency discrimination in normal vision and in patients with multiple sclerosis. Brain, 1982, 105, 735-54.
  129. Regan D. Spatial frequency mechanisms in human vision investigated by evoked potential recording. Vision Res, 1983, 23, 1401-8.
  130. Regan D. Visual psychophysical tests in the diagnosis of multiple sclerosis. In C.M. Poser (Ed.), The diagnosis of multiple sclerosis. New York: Thieme-Stratton, 1984, 64-75.
  131. Regan D. Visual sensory aspects of simulators. In W. Richards & K. Dismukes (Eds.), Vision research for flight simulation. Washington: National Academy Press, 1982, pp 65-71.
  132. Regan D. & Beverley K.I. Visual fields for frontal plane motion and for changing size. Vision Res, 1983, 23, 673-6.

133. Regan, D. & Beverley, K. I. Visual fields for frontal plane motion and for changing size. Vision Res, 1983, 23, 673-676.
134. Quine, D. B., Regan, D. & Murray, T. J. Degraded discrimination between speech-like sounds in multiple sclerosis and in Friedreich's ataxia. Brain, 1984, 107, 1113-1122.
135. Kruk, R. & Regan, D. Visual test results compared with flying performance in telemetry-tracked aircraft. Aviat Space Environ Med, 1983, 54, 906-911.
136. Regan, D. Temporal factors in color discrimination. J Opt Soc Am.
137. Regan, D., Beverley, K. I. & Macpherson, H. Pattern visual evoked potentials in amblyopic children. Proc 2nd Intl Evoked Potentials Conf, Cleveland, 1984.
138. Regan, D. & Beverley, K. I. Figure-ground segregation by motion contrast and by luminance contrast. J Opt Soc Am, 1984, 1, 433-442.
139. Regan, D. & Beverley, K. I. Spatial frequency discrimination and detection: comparison of postadaptation thresholds. J Opt Soc Am, 1983, 73, 1684-1690.
140. Regan, D. & Neima, D. Low-contrast letter charts as a test of visual function. Ophthalmology, 1983, 90, 1192-1200.
141. Neima, D. & Regan, D. Pattern visual evoked potentials and spatial vision in retrobulbar neuritis and multiple sclerosis. Arch Neurol, 1984, 41, 198-201.
142. Neima, D., LeBlanc, R. & Regan, D. Visual field defects in ocular hypertension and glaucoma. Arch Ophthalmol, 1984, 102, 1042-1045.
143. Regan, D. & Neima, D. Visual fatigue and VEPs in multiple sclerosis, glaucoma, ocular hypertension and Parkinson's disease. J Neurol Neurosurg Psychiat, 1984, 47, 673-678.
144. Regan, D. & Neima, D. The balance between pattern and flicker sensitivities in the visual fields of ophthalmological patients. Br J Ophthalmol, 1984, 68, 310-315.
145. Regan, D. & Beverley, K. I. Visual responses to vorticity and the neural analysis of optic flow. J Opt Soc Am A, 1985, 2, 280-283.
146. Burbeck, C. A. & Regan, D. Independence of orientation and size in spatial discriminations. J Opt Soc Am, 1983, 73, 1691-1694.
147. Regan, D. The relation between apparent spatial frequency and spatial frequency discrimination. Vision Res, submitted.
148. Regan, D. Evoked potentials and their applications to neuro-ophthalmology. Neuro-ophthalmology, 1985, 5, 73-108.
149. Regan, D. & Beverley, K. I. Postadaptation orientation discrimination. J Opt Soc Am A, 1985, 2, 147-155.

150. Regan, D. & Neima, D. Low contrast letter charts in early diabetic retinopathy, ocular hypertension, glaucoma and Parkinson's disease. Br J Ophthalmol, 1984, 68, 885-889.
151. Regan, D. Masking of spatial frequency discrimination. J Opt Soc Am A, 1985, 2, 1153-1159.
152. Spekreijse, H., Dagnelie, G., Maier, J. & Regan, D. Flicker and movement constituents of the pattern reversal response. Vision Res, submitted.
153. Wilson, H. R. & Regan, D. Spatial frequency adaptation and grating discrimination: predictions of a line element model. J Opt Soc Am A, 1984, 1, 1091-1096.
154. Regan, D. New visual sensory tests in neurology and ophthalmology. In A. Starr (Ed.), Proc 7th Evoked Potential Workshop, University of California, Irvine, 1984. Milan: Amplifon, 1985, 101-119.
155. Regan, D. Visual processing of four kinds of visual motion. Workshop on "Systems Approaches in Vision", Royal Society of the Netherlands 1984, in honour of H. van der Tweel. Vision Res, 1986, 26, 127-145.
156. Regan, D. Storage of spatial-frequency information and spatial-frequency discrimination. J Opt Soc Am A, 1985, 2, 619-621.
157. Regan, D. Visual flow and direction of locomotion: reply. Science, 1985, 227, 1063-1065.

2d. PROFESSIONAL PERSONNEL

D. Regan, Ph.D., D.Sc., A.R.C.S., Professor of Ophthalmology and Medicine

Joint research was carried out with M. Morgan, Ph.D. (Professor of Psychology, University College, London, England); H. Collewyn, M.D. (Professor of Physiology, Erasmus University, Rotterdam, Holland); C. Erkelens, Ph.D. (Erasmus University).

2e. INTERACTIONS

Interactions with Armed Forces

Session chairman at Tri-Services meeting on vision, Pensacola.

Invited paper on vision in aviation at Tri-Services meeting, Pensacola.

Joint research with U.S. Navy (Pensacola, Cmdr Wm. Monaco) on visual tests in Navy pilots.

Joint research with Essex Corp (Dr. R.S. Kennedy, Orlando) on the use of our motion-in-depth tracker and flow pattern tests in predicting flying performance in Navy pilots.

Papers presented at meetings, conferences, seminars etc

Spekreijse, H., Dagnelie, G., Maier, J. & Regan, D. Flicker and velocity constituents of the motion response. Association for Research in Vision and Ophthalmology (ARVO), Sarasota.

Regan, D. & Beverley, K.I. Postadaptation orientation discrimination. Association for Research in Vision and Ophthalmology (ARVO), Sarasota.

Regan, D. Opponent processes in visual hyperacuties. European Vision Research Conference, Cambridge, England.

Formal lectures

J. Olszewski lecture to the Canadian Association of Neuropathologists, Halifax, Canada.

Seminars

Bolling Air Force Base, D.C.

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